SAMPLING DESIGN FOR INTEGRATED NONCASH AND ECONOMIC VALUATION OF BIODIVERSITY – CASE STUDY

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Biodiversity is the keystone of the ecosystem functioning, from which all functions are derived. The present paper deals with the sampling design aimed at integrated evaluation and valuation of biodiversity. The sampling design was applied in the area of the Forest Establishment of the Czech University of Life Sciences (CULS UFE) at Kostelec nad Černými lesy, which is characterized by heterogeneous site and landscape conditions. The information from two data sources was used for the area stratification and the proposal of the sampling design: (1) database of forest management plans; and (2) bitmapped layers of characteristics derived by common tools of GIS. The analysis of these data resulted in the identification of the three main stratificators, which significantly influence both the economic value of timber and the species richness – an important indicator of biodiversity. The stratificators are age category, stocking, and site category. Based on these stratificators the area was divided into 132 strata. Within these strata a broad spectrum of information was investigated using a two-phase sampling process. The suitability of the proposed sampling design was proven by the validation analysis of the collected inventory data.

stratification; GIS analysis; two-phase sampling; forest ecosystem

INTRODUCTION

The evolution of the planet Earth, its individual periods and eras, has formed environmental conditions in every corner to a great extent. The specific features of abiotic environment are the basics in the formation of specific life forms and communities. Hence, the diversity of abiotic components is closely coupled with the diversity of biotic components. The term biological diversity (shortened as biodiversity) occurred in the scientific literature firstly in 1972 (Kaennel, 1998). While in the 70s and at the beginning of the 80s of the last century, this term referred to "number of present species" (Christie et al., 2004), nowadays there exists a number of formal and informal definitions of the term biodiversity (Kaennel, 1998). The most common definition of biological diversity is given in the Convention on Biological Diversity. This document defines biodiversity as 'the variety and variability among living organisms from all sources including inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part'. This definition covers three fundamental components of diversity: genetic, species, and ecosystem diversity (Duelli, 1997; Kaennel, 1998).

Even more important than to define the term biodiversity is to understand its significance from the point of ecosystem functioning and human well-being. Biodiversity itself has its own intrinsic value (Nunes, van den Bergh, 2001). In addition, due to everything that biodiversity provides starting from food, medicine, through building and construction materials, up to satisfying spiritual, cultural, and aesthetic needs, it has a multiple importance for mankind (Scholes et al., 2006) as well as for the preservation of life on the Earth (Munasinghe, 1992).

Within the framework of multi-purpose forest management, biodiversity is usually considered as one of the forest functions along with production, recreation function of forests, while according to biodiversity definition and its partial components, these functions are integral elements of biodiversity. Biodiversity represents the fundamental keystone, the basis of ecosystem functioning, from which individual functions are derived. The objective of this paper is to present the sampling design aimed at integrated nonmonetary evaluation and economic valuation of biodiversity.

MATERIAL AND METHODS

For the present study, the Forest Establishment of the Czech University of Life Sciences at Kostelec nad Černými lesy, Czech Republic (CULS UFE) was chosen

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as a pilot area (Fig. 1). The area of the enterprise is 5910 ha. Forest cover of the enterprise makes 95.4% calculated as a proportion of the forest area from the total area of the enterprise including meadows, etc. As can be seen in Fig. 1, the enterprise is fragmented, particularly in its eastern part. The area is heterogeneous covering five forest altitudinal zones (pine, oak, oak-beech, beech, and fir-beech). Mean annual temperature varies from 7.0 to 7.5ºC, mean temperature in growth period ranges 13.0–13.8ºC. Growth period lasts 153 days on average. Mean annual precipitation is 600–650 mm.

The stratification of the area and the proposal of the sampling design are based on the information obtained from two data sources. The first data source is the database of forest management plans of individual spatial forest units at the lowest level. The second data source consists of raster layers of variables derived with common GIS tools.

The information representing forest stand units was prepared by combining and summarizing the information from lower hierarchical levels (storey, tree species) and consists of the information about site, forest stand structure, diversity, and timber price. Timber price was derived from the stand assortment based on the assortment tables by Petráš, Nociar (1990, 1991). From these data the following information was derived: (1) age category (in years): (0: clearing, 1: 1–20, 2: 21–40, 3: 41–60, 4: 61–80, 5: 81–100, 6: 101–120, 7: 121–140, 8: above 141, 9: both maximum and minimum age < 40, 10: maximum age ≥ 40 and minimum age ≥ 30, 11: maximum age > 80 and minimum age < 30), (2) stocking category (sum of stockings – 1: 0–2, 2: 3–4, 3: 5–6, 4: 7–8, 5:above 9), (3) timber price per ha. Classification of altitudinal zones and soil categories followed the Czech forestry typology (ÚHÚL, 2003). The area of the enterprise covers five altitudinal zones and 20 soil categories.

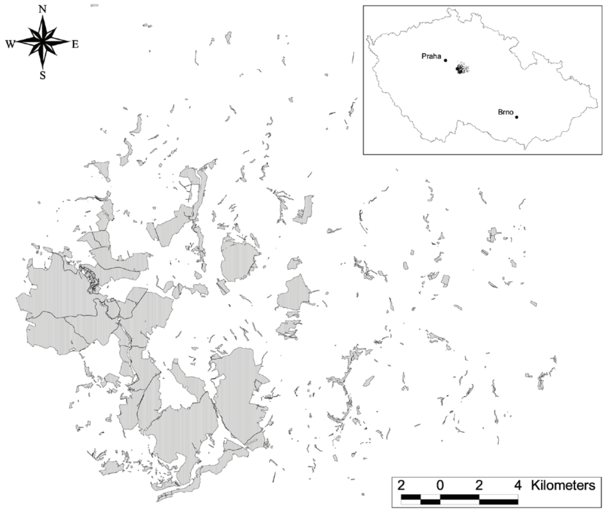

Fig. 1. The forest management unit University Forest Establishment Kostelec nad Černými lesy

SAGA GUI software (SAGA User's Manual, 2008) was applied to derive raster information. In the first step, digital terrain model (DTM) of the whole forest management unit Kostelec nad Černými lesy was derived from the contour map with 10 × 10 m resolution. DTM was created using multi-stage B-Spline interpolation (Lee et al., 1997). Afterwards, GIS tools were applied to derive 12 raster layers with the same resolution for the following characteristics: slope (°), aspect (°), curvature classification (9 categorical variables defining slope concavity and convexity along its fall line and contour line), convergence index (a measure of how flow in a cell diverges (convergence index < 0) or converges (convergence index > 0)), erosion index – LS Factor, topographic wetness index (TWI), SAGA wetness index (similar to TWI, but based on a modified catchment area calculation, which does not consider the flow as very thin film; hence, for the cells situated in the valley bottom with a small vertical distance to a channel the predicted soil moisture is more realistic, with higher potential compared to the standard TWI calculation – Boehner et al., 2002), catchment slope SAGA (2008), analytical hill shading, channel network base level, solar radiation (potential incoming solar radiation according to Wilson, Gallant, 2000), duration of insolation (Wilson, Gallant, 2000).

With GIS tools, the derived raster information was coupled to the data from forest management plans. The interconnected raster information is an arithmetical average from the raster points that represents the particular spatial forest unit segment.

To identify the influence of the variables on species richness and timber price, we applied main effects analysis of variance (ANOVA), as this analysis is recommended in highly fractionalized and incomplete designs. In the next step, cluster analysis was applied to specify site categories. Cluster analysis uses categorical variables to classify the analyzed objects into a smaller number of categorical classes, which are more homogeneous as they group objects with similar features.

RESULTS

Analysis of the relationship between the independent variables and market timber price or species richness

Tables 1 and 2 show the results of the analysis of variance of the main effects, which examined the relationship between the characteristics derived from the two data sources and timber market price or species richness. The results presented in Table 1 show

Table 1. Main effects analysis of variance of the influence of selected variables on market timber price per ha

Main factor	*F* statistics	*P* level
Age	4421.6	0.000
Stocking	364.2	0.000
Forest altitudinal zone	96.4	0.000
Group of forest types (GFT)	26.1	0.000
Altitude	13.1	0.000
Soil	11.8	0.000
Number of species per forest stand group	7.5	0.000
SAGA wetness index	5.1	0.000
Aspect	4.4	0.000
Channel network base level	3.4	0.000
Curvature classification	3.2	0.012
Convergence index	1.9	0.047
Topographic wetness index	1.9	0.048
Solar radiation	1.6	0.122
LS factor	1.2	0.293
SAGA catchment slope	1.1	0.356
Slope	1.1	0.393
Number of storeys	1.0	0.327
Analytical hillshading	0.7	0.677

Table 2. Main effects analysis of variance of the influence of selected variables on tree species richness

Main factor	*F* statistics	*P* level
Age	130.3	0.000
Forest altitudinal zone	25.3	0.000
Stocking	15.0	0.000
Altitude	14.7	0.000
Group of forest types (GFT)	8.2	0.000
Soil	7.5	0.000
Curvature classification	4.5	0.001
Solar radiation	4.2	0.000
Aspect	3.9	0.000
Slope	3.3	0.000
Channel network base level	2.8	0.003
Topographic wetness index	2.1	0.028
SAGA wetness index	2.0	0.035
Number of storeys	1.8	0.186
LS factor	1.2	0.310
Analytical hillshading	0.6	0.808
Convergence index	0.5	0.877
SAGA catchment slope	0.5	0.886

that timber price is mostly influenced by age category, stocking category, forest altitudinal zone, altitude, and soil category.

Similar analysis was performed to examine the influence of the selected factors on tree species richness (Table 2). This analysis revealed similar results: the most influencing factor was age category, followed by forest altitudinal zone, stocking category, and soil category.

The results from both analyses enable us to distinguish the general main factors and hence, to reduce the number of variables that influence both species richness and timber price most. The main factors are age category, stocking category, forest altitudinal zone, and soil category. The last two variables can be aggregated into one forestry variable: a group of forest types (GFT), which was also found to be significant (Tables 1, 2).

In the Kostelec forest management unit, 46 different groups of forest types (GFT) are present. However, not all the levels of GFTs have a significant influence on species richness or timber price. In addition, number 46 is quite high regarding our intention to combine all principal factors for strata specification, which would lead to a very high number of combinations. Due to these facts, we aggregated all present GFTs into 5 site categories with regard to the similarities of GFTs in species richness and timber price per hectare (Fig. 2). The aggregation was performed by cluster analysis. To ensure that the analyzed variables are of equal weight, number of tree species and timber price per hectare were indexed to their maximum values in the particular GFT.

In this way, we defined a new variable named 'site category', which has a greater influence than GFT (*F* value has risen from the original 26.1 and 8.0 to 82.4 and 17.6 for timber price and species richness, respectively). As seen in Fig. 2, each site category represents localities characterized by a different combination of timber market price and tree species richness. For example, site category 3 represents localities with

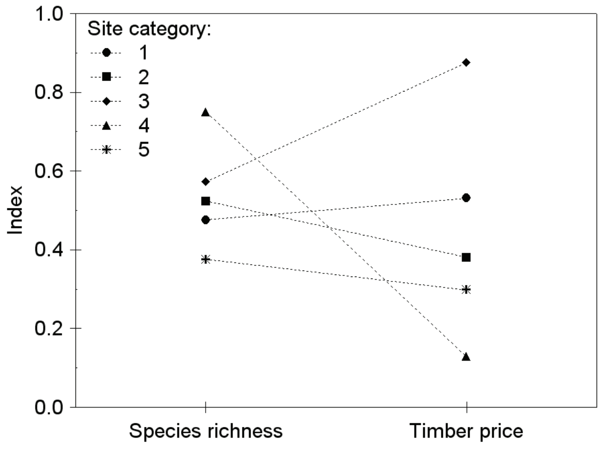

Fig. 2. Relationship between site categories and species richness and timber price per ha

both high tree species richness and timber price. Site category 4 includes the sites with high tree species richness, but low timber price, while the sites grouped in site category 5 are characterized by both low tree species richness and low timber price (Fig. 2).

In the next step, the area of the forest enterprise was stratified using the three stratificators: age category, stocking category, and site category. The stratification divided the area into 132 strata. Each stratum is identified by a 4-digit number, where the 1st digit indicates site category (5 categories), the 2nd and 3rd digits indicate age category (12 categories), and the 4th digit indicates stocking category (5 categories). The areas of individual strata vary from 0.06 to 687.3 ha. Each stratum consists of a different number of polygons specifically arranged over the pilot area. From the total number, 33 strata have more than 35 polygons with the total area ranging from 8.4 to 687.3 ha. The area of 76 strata is larger than 1.5 ha.

Proposal of sampling design

Sampling design is related to the decisions dealing with the type of sampling units (sampling plots), their spatial distribution, and their number which have an effect on accuracy, costs, and arrangement of inventory works. A sampling plot is a basic sampling unit in which all the variables of the information spectrum are assessed.

Based on the analysis presented above, the applied sampling design used stratification principles coupled with the principles of two-phase sampling. Hence, in the individual strata the data were gathered in two phases. In the 1st phase, the information was assessed in each sampling unit in a quick way, while in the 2nd phase the most important variables were measured in a more accurate way using precise Field-Map technology (IFER – Institute of Forest Ecosystem Research, Ltd., Jílové u Prahy, Czech Republic, available from: http://www.ifer.cz/page/?page=fieldmapfor) in a subset of sampling plots.

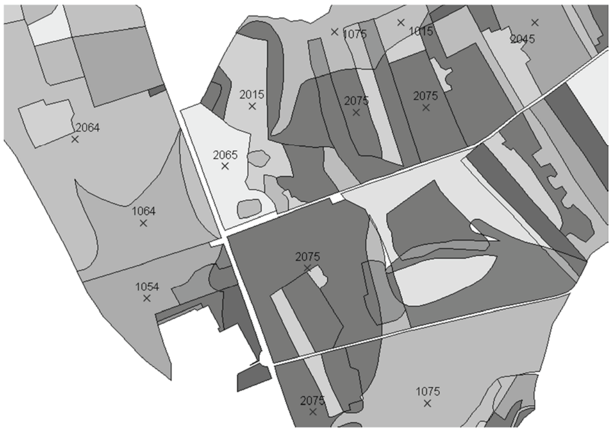

Fig. 3. Detail of the area stratification with generated sampling plots using randomized sampling (plot No. 2015 means that the plot is in site category 2, forest stand age 1–20 years, stocking above 9)

Sampling system, i.e. the spatial distribution of sampling units over the studied area, is the result of the randomized sampling and subjective stratification sampling in order to ensure that the plot represents all three stratificators. Density of the sample plots in each stratum was optimized to the assumed variation of the complex biodiversity indicator and the required accuracy of the sampling result. We estimated that 30 plots are required for the 1st phase, and 7–8 plots are needed for the 2nd phase.

In large strata, for which the number of polygons larger than the area of one sampling plot was greater than 30, randomized sampling design was applied (Fig. 3). The centres of the sampling plots were situated in the centroids of the polygons of the particular stratum. In these strata, the sampling plot was of an area of 500 m^2 and its shape was either circular, or quadratic, or rectangular.

In the strata of a small size (i.e. with the area smaller than the area of the sampling intensity per stratum, which is 1.5 ha under the assumption that 30 sampling plots, each of 0.05 ha in size, are established in the stratum (30 × 0.05 ha = 1.5 ha)), the shape of the sampling unit was adjusted to the shape of the partial polygon, and the data were gathered over the whole area of the stratum.

In each sampling plot, more than 50 different variables describing tree species, deadwood, shrubs, plants and other data determining forest functions, were assessed. The gathered information was of a qualitative (descriptive) or a quantitative (measurable) nature. Qualitative parameters were assessed visually and by assigning a specific object (e.g. site, stand, tree, etc.) into a particular pre-defined category (class, e.g. tree species). Quantitative variables are either measured or estimated in a specific unambiguous way, and are given in a numerical value with a pre-defined number of decimal places.

Analysis of the influence of the main stratificators on species richness and timber price – validation of the proposed design

During field works in 2009–2011, 86 strata were inventoried and 1188 inventory plots were established. From the total of 1626 recordings about the forest structure, 1188 recordings were gathered in the 1st inventory phase in a quick way and 438 recordings in the 2nd phase by detailed measurements. We applied the main effects analysis of variance to the collected data to test if the proposed sampling design met our assumptions.

In the inventory plots, tree species richness was assessed at three different levels: tree species richness of small trees below diameter threshold (i.e. with diameter at breast height below 7 cm), tree species richness of trees above threshold (i.e. with diameter at breast height equal to or above 7 cm), and the total tree species richness of all trees. Timber price of standing timber was calculated using the assortment tables for the main tree species of the former Czechoslovakia (Norway spruce, Scots pine, European beech, oak), which were prepared by Pařez, Michalec (1987), and the timber prices of individual assortments published by the Czech Statistical Institute for the year 2010.

As can be seen in Table 3, the assumptions of the design have been met. The influence of all stratificators on the timber price was found to be significant. Similarly as in the design proposal, age had the most significant influence followed by stocking and site. In case of species richness, statistical significance of age was found for all three levels of species richness. Although the influence of site and stocking was not proven to be significant, their effects are at the significance threshold. This can be caused by the fact that species richness used as a stratificator represents the stand level, while the analyzed species richness represents a plot level, i.e. it refers to 0.05 ha, which is an area of one inventory plot. The data obtained from forest management plans, which were used for the design proposal, cannot be easily transformed to represent the same area. We assume that this difference between the two approaches caused the differences of the results.

Table 3. Main effects analysis of variance of the influence of selected main stratifications variables on tree species richness and timber price

Effect	Variable	*F* statistics	*P* level
Site category	species richness (DBH < 7 cm)	0.58	0.678
Age category		8.35	0.000*
Stocking category		0.90	0.464
Site category	species richness (DBH ≥ 7 cm)	1.78	0.130
Age category		8.37	0.000*
Stocking category		0.98	0.420
Site category	species richness (All)	1.24	0.293
Age category		10.43	0.000*
Stocking category		2.07	0.083
Site category	timber price	13.02	0.000*
Age category		103.11	0.000*
Stocking category		67.47	0.000*

DBH = diameter at breast height; All = all trees

*significance level 99.9%

DISCUSSION

Several papers have dealt with the sampling strategies with regard to biodiversity inventory (Gimaret-Carpentier, 1998; Vanclay, 1998; Alberdi et al., 2010; Corona et al., 2011; Jayakumar et al., 2011). The approaches used for assessing biodiversity vary in the applied sampling design, intensity, criteria, and costs (Gimaret-Carpentier et al., 1998; Newton, Kapos, 2002; Jayakumar et al., 2011) depending on the goal of the particular study.

Similarly to our study, many authors suggested to stratify the assessed area according to an important factor to consider the influence of topographic and climatic conditions (Gimaret-Carpentier et al., 1998; Vanclay, 1998; Alberdi et al., 2010; Corona et al., 2011). Stratified sampling brings several advantages for biodiversity assessment. It ensures that different habitats are adequately represented, and enable a more detailed survey of biodiversity in a particular habitat (Corona et al., 2011). It also reduces the standard error of sampling and provides us with the estimates for each stratum as well as for the whole population (Shiver, Borders, 1996). Common stratificators are forest types since they represent more homogeneous units characterized by key determinants of forest diversity (Corona et al., 2011). The determinants are usually tree species and/or site factors (Corona et al., 2004). Forest types are also related to ground vegetation (Alberdi et al., 2011). Hence, they represent a set of habitat factors (Stokland et al., 2003). Since a great number of forest types has been distinguished on both national and European levels, several authors, e.g. Barbati, Marchetti (2004), have suggested a simplified categorization with fewer categories for biodiversity assessment. For example, on European level Bohn et al. (2000) distinguished 699 potential forest types (Bradshaw, Møller, 2005), while Barbati, Marchetti (2004) simplified the categorization into 14 forest types.

Hence, we can state that the sampling design proposed here follows the up-to-date trends in biodiversity assessment worldwide. In our sampling scheme, the stratificator site category was derived by grouping the groups of forest types with similar values of species richness and timber price per hectare. The two other stratificators, i.e. age and stocking, further reduce heterogeneity of the population. The inventory is statistically-based, which is a good pre-requisite for spatial and temporal analysis and comparisons.

By comparing our approach with the published works we can state that the attempt to combine the nonmonetary and monetary biodiversity assessment is original and new. Baumgärtner (2007) stated that there exists a great disproportion between the perception of biodiversity from the ecological and economical points of view. Similarly, there is a great discrepancy in the quantification and valuation of biodiversity, primarily because these two dimensions are ususally applied separately and their relationships are rarely studied (Vierikko et al., 2010). The only work that has made an attempt to combine both approaches was published by Ojea et al. (2010), who suggested an economical forest value based on the values of ecosystem goods and services as well as on some biodiversity indicators (e.g. number of species and number of threatened species).

CONCLUSION

The present paper identifies significant variables that are important for the proposal of the sampling design for the quantification of nonmonetary and monetary value of biodiversity. The significant variables were identified using modern computer-based tools such as geographic information systems and multivariate statistical methods. The results revealed that for the stratification of the area three variables are significant: age category, site category, and stocking. A simple validation analysis of data obtained from the field inventory in 2009–2011 revealed the suitability of the applied design.

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Výběrový design pro komplexní nepeněžní a peněžní hodnocení biodiverzity – případová studie

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Biodiverzita je klíčovým prvkem fungování ekosystému, ze kterého jsou odvozené všechny jeho funkce. V předkládaném příspěvku prezentujeme výběrový dizajn pro komplexní nepeněžní a peněžní hodnocení biodiverzity. Výběrový design se aplikoval na území školního lesního podniku Kostelec nad Černými lesy, pro který jsou charakteristické variabilní stanovištní podmínky. Pro stratifikaci území a návrh výběrového designu byly použity údaje ze dvou zdrojů: (1) databáze lesních hospodářských plánů a (2) rastrové vrstvy veličin odvozených běžnými nástroji GIS. Analýzou dat byly vymezeny tři hlavní stratifikátory, které významně ovlivňují ekonomickou hodnotu dřevní hmoty a druhovou bohatost jako důležitého indikátoru biodiverzity. Stratifikátory jsou věková kategorie, zakmenění a stanovištní kategorie. Pomocí těchto stratifikátorů bylo na území vymezeno 132 strat, v rámci kterých se zjišťovalo široké spektrum informací za použití dvojfázového výběru. Vhodnost navrhovaného výběrového designu byla prověřena validační analýzou na inventarizačních datech.

stratifikace; GIS analýza; dvoufázový výběr; lesní ekosystém

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